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Test-retest reliability of stride length-cadence gait relationship in Parkinson's disease

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ABSTRACT

Introduction: The gait pattern in Parkinson´s disease (PD) subjects is characterized by a specific deficit of the internal regulation of the stride length (SL), while the control of the cadence (Cad) remains intact. The purpose of the present study was to evaluate the reliability of the stride length-cadence relationship (SLCrel) in a group of PD subjects.

Methods: Thirty five PD subjects performed two sessions, separated by a three month resting period. In each session Gait speed, SL and Cad were evaluated at five different self-selected speed conditions: preferred, slow, very slow, fast and very fast. Linear regression analysis was used to explore the SLCrel and to determine the slope, intercept and coefficient of determination (R^2) for each participant. Test-retest reliability for the slope and intercept was calculated using intra-class correlation coefficient (ICC), 95% confidence interval (CI), and standard error of mean (SEM).

Results: There were no significant differences in the slope and intercept between the two sessions. The overall speed was significantly faster in the second session compared with the first one ($F = 4.60$, $p = 0.03$). The SLCrel showed high reliability across the sessions (ICC = 0.89 and ICC = 0.91; 95% CI = 0.80 − 0.95 and 95% CI = 0.82 − 0.95; SEM = 0.002 and SEM = 0.073, for the slope and interception, respectively).

Conclusions: The SLCrel in Parkinsonian gait is a reproducible measure across a period of three months, and may be a useful tool to explore the specificity of gait rehabilitation interventions in PD subjects.

1. Introduction

Parkinson's disease (PD) is a neurodegenerative disease, clinically characterized by akinesia, rigidity, tremor and postural instability [1]. Gait disturbances are one of the principal and most incapacitating symptoms of PD. Gait in PD is characterized by shorter stride length, forward-flexed trunk, inadequate flexion at the ankle and knee, insufficient heel strike, reduced arm swing, postural instability, asymmetric stride for lower limbs, and higher stride-to-stride variability in comparison with age/sex matched controls [2].

The gait pattern in PD subjects is also characterized by a specific deficit of the internal regulation of the stride length (SL), while the cadence control is intact [3]. When healthy adults increase or decrease their self-selected walking speed, they increase or decrease their SL and cadence in a relatively constant linear relationship [4,5]. In PD subjects, the slope of this relationship remains unaffected, while the interception is smaller than that in healthy subjects, that is, a smaller stride length is associated with a higher cadence [6]. This difficulty in the regulation of the SL can be normalized by using attentional strategies [6] or in response to Levodopa medication [7], suggesting that PD subjects have the ability to generate a normal stride length-cadence relationship (SLCrel) [6]. Thus, the regulation of the SL represents one of the main goals in rehabilitation interventions in PD subjects. However, the effects of physical therapy interventions on the SLCrel in PD subjects have not been examined. Most of the studies that evaluated the efficacy of rehabilitation and exercise interventions used, independently, changes in SL, cadence or speed as the main outcome measures [8]. Thus, although, increases in gait speed may reflect a functional improvement [8], these do not necessarily reflect an amelioration of PD symptomatology. In addition, due to the age-associated progressive loss of physical function, it is difficult to elucidate which rehabilitation approach has a specific impact in PD rather than a generalized benefit from exercise [9]. The study of the SLCrel may help to establish the specific therapeutic effect of an intervention, in order to optimize the

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Table 1
Group characteristic.

Age, yrs	63.43 ± 9.47
Male, n	23
Female, n	12
Weight, kg	76.56 ± 12.33
Height, cm	164.06 ± 9.45
Leg length, cm	83.54 ± 5.82
MMSE	26.80 ± 2.43
Disease duration, yrs	6.26 ± 4.49
UPDRS-III	17.66 ± 8.59
H&Y stage (subject in each stage)	1 (n = 7); 1.5 (n = 7); 2 (n = 17); 2.5 (n = 4)

Note. Means ± SD unless stated otherwise; MMSE Mini Mental State Examination, UPDRS-III Unified Parkinson's Disease Rating Scale motor section, H&Y Hoehn and Yahr.

rehabilitation strategy. The reliability of SLCrel in PD subjects has not been examined, and this is of relevance since most of the measures that are used in physical therapy suffer from a lack of reliability [8].

The objective of the present study was to evaluate the reliability of the SLCrel in a group of PD subjects. We used a previously reported protocol [4,10], in order to explore the SLCrel in two sessions, separated by a period of three months. We choose this period of time since most of the physical therapy studies used similar periods of intervention [11]. We determined the reliability of the SLCrel as an outcome measure in Parkinson's rehabilitation interventions.

2. Methods

2.1. Participants

Thirty five PD subjects participated in the study (23 males and 12 females, mean age = 63.43 ± 9.47 (Table 1)). To participate in the study, PD subjects had to be able to walk without assistance, and did not take medication that could influence their walking ability negatively (i.e. antidopaminergic medications). The recording sessions were performed with subjects in "ON" medication state (45–90 min after medication intake), as confirmed by a neurologist. All the subjects showed no sign of dementia as assessed by a mini-mental state examination (MMSE scores ≥ 23) [12]. The level of severity of motor signs associated with PD was measured using the Unified Parkinson's Disease Rating Scale Part-III (UPDRS-III) [13] and Hoehn and Yahr scale (H&Y) [1]. Height, weight and leg length were evaluated for each subject. All the participants gave their written informed consent according to the declaration of Helsinki. The experimental procedures were approved by the ethics committee of the University of A Coruña.

2.2. Procedure

Participants performed two testing sessions (T1, T2) with a three month period between the tests (average days between sessions 89.48 ± 2.46). The two testing sessions were conducted at the same time of the day and under similar environmental conditions. During the three month period, the subjects did not change their daily activities or medication. None of the subjects reported any event such as falls or change of medication. UPDRS-III scores were also measured at T2.

2.3. Gait measurements

Kinematic gait parameters were evaluated using an optical detection system and software (v,1,11OptoGait; Microgait, Italy). This optical and modular system included transmitting and receiving bars of infrared LEDs displayed in parallel along 5 m of a 9 m walkway. Each bar contained 100 LEDs. When subjects entered the area limited by the bars, their feet blocked the transmission and reception, and the spatiotemporal gait data was transfered to a personal computer at a sample rate of 1000 HZ. The OptoGait System has strong concurrent validity along with relative and absolute test-retest reliabilities [14].

We followed the protocol previously used in several studies [4,10]. Gait speed, SL and cadence were evaluated at five different self-selected speed conditions: preferred, slow, very slow, fast and very fast. All the patients performed three consecutive trials for each self-selected speed condition. Each trial consisted of walking from one end of the walkway and back. Trials at the preferred self-selected speed condition were always recorded first in order to avoid any influence from other conditions. The remaining four self-selected speed conditions were performed in one of the following orders to counterbalance the order effect: slow, very slow, fast and very fast, or, fast, very fast, slow and very slow. Participants were randomly allocated to one of the two orders. For each trial participants started to walk two meters before the electronic walkway and finished two meters beyond the walkway, in order to avoid recording the acceleration and slowing down of the subjects. The second and third walks of each self-selected speed condition were averaged, to obtain one value per participant. PD patients rested between self-selected speed conditions as required. Participants had only one practice trial at their preferred self-selected speed condition in order to familiarize themselves with the spatial dimensions of the laboratory. We explained to the subjects at the beginning of the experiment that they will have to walk at five different self-selected speed conditions. All the participants understood the explanations and performed all the five self-selected speed conditions without any difficulty.

We analyzed the following gait variables: speed, SL and cadence. SL was normalized by dividing mean SL for each self-selected speed condition by the leg length [15]. The leg length was defined as the distance measured from the greater trochanter to the plane of the sole of the foot [16]. Linear regression analysis was used to evaluate the SLCrel and to determine the slope, intercept and R^2 for each participant. A linear relationship between SL and cadence was defined as that having R^2 values that were greater or equal to 0.80 [10]. Although, previous studies have reported intercept values at a cadence of zero [3,6], the validity of values outside the range of the data may be questionable [17]. Therefore, and following previous studies [4,10,18], we calculated the intercept for cadence using the value of 100 steps/min, to ensure that the intercept values were within the data range for all the participants [4,10,18].

2.4. Statistical analysis

Gait comparisons, of the variables SL, cadence, and speed, were evaluated using ANOVA of repeated measurements, with SESSION (T1, T2) and CONDITION (slow, very slow, preferred, fast and very fast self-selected speeds) as factors. Post-hoc analysis was conducted using a Bonferroni adjustment.

Paired-samples-t-tests were used to compare UPDRS-III scores, the intercept and slope between T1 and T2. Test-retest reliability for the slope and intercept was calculated using the intra-class correlation coefficient (ICC), the corresponding 95% confidence interval, and the standard error of mean (SEM). ICC is a relative measure of reliability, reflective of the ability of a test to differentiate between different individuals. The SEM centers on the assessment of reliability within individual subjects, quantifying the precision of individual scores on a test [19]. In addition, we also calculated the minimal important difference (MID), where MID = SEM x 1.96, a value that distinguishes between true and apparent change due to a measurement error [19,20], thus determining which changes resulted from a hypothetical therapy.

All the data were analyzed using IBM SPSS Statistics for Windows (v.24.0.0). None of the data violated the normality assumption necessary to conduct parametric statistical tests. Significance level was set at $p \leq 0.05$.

Table 2
Gait parameters for speed conditions during T1 and T2.

	T1 (n = 35) Mean (SD) Min, Max	T2 (n = 35) Mean, SD, Min, Max
Condition VS (m/sec)	0.84 (0.15), 0.51, 1.07	0.87 (0.16), 0.55, 1.28
Condition S (m/sec)	1.02 (0.15), 0.70, 1.28	1.05 (0.17), 0.75, 1.48
Condition Pref (m/sec)	1.20 (0.16), 0.89, 1.52	1.25 (0.19), 0.82, 1.64
Condition F (m/sec)	1.34 (0.19), 0.97, 1.68	1.38 (0.21), 0.98, 1.86
Condition VF(m/sec)	1.52 (0.24), 1.09, 1.98	1.54 (0.23), 1.10, 2.08
nSL VS	1.05 (0.13), 0.75, 1.23	1.08 (0.16), 0.84, 1.51
nSL S	1.15 (0.14), 0.90, 1.39	1.18 (0.17), 0.90, 1.68
nSL Pref	1.26 (0.14), 0.95, 1.56	1.28 (0.18), 0.97, 1.77
nSL F	1.33 (0.15), 1.02, 1.65	1.36 (0.18), 1.03, 1.83
nSL VF	1.42 (0.18), 1.07, 1.82	1.42 (0.19), 1.06, 1.91
Cad VS (step/min)	95.94 (10.09), 71.4, 114.5	96.63 (9.70), 73.2, 1.20
Cad S (step/min)	105.56 (9.09), 85.6, 122.4	106.97 (9.26), 0.88, 1.26
Cad Pref (step/min)	114.03 (8.39), 99.3, 132.3	116.50 (8.92), 0.96, 1.32
Cad F (step/min)	121.09 (10.46), 101.5, 142.8	122.65 (9.65), 1.03, 1.44
Cad VF (step/min)	129.24 (11.84), 107.4, 148.8	130.13 (11.43), 1.09, 1.59

Note. SD; standard deviation, Min; minimum, Max; maximum, VS; very slow, S; slow, Pref; preferred, F; fast, VF; very fast; nSL, normalized stride length; Cad, cadence.

3. Results

There were no significant differences in the UPDRS-III scores between T1 (17.66 ± 8.59) and T2 (18.74 ± 9.01).

3.1. Modulation of gait speed, stride length and cadence

Descriptive statistics of the variables that were obtained in the two recording sessions are presented in Table 2.

Two-way ANOVA for gait speed showed a significant main effect for SESSION (F = 4.60, p = 0.03) and CONDITION (F = 122.02, $p < 0.001$). There was no significant SESSION x CONDITION interaction. The overall gait speed was significantly higher in the second session in comparison with the first one. The post-hoc analysis revealed the faster the self-selected speed conditions (grouping both sessions), the faster the gait speed ($p < 0.001$ for all comparisons).

Two-way ANOVA for SL showed a significant main effect for CONDITION (F = 95.34, $p < 0.001$). We did not show a significant effect for SESSION, although there was a tendency for significance (F = 3.68 P = 0.059). There was no significant SESSION x CONDITION interaction. Post-hoc analysis revealed that the faster the self-selected speed conditions the longer the SL ($p < 0.001$ for all comparisons).

Two-way ANOVA for cadence revealed a significant main effect for CONDITION (F = 76.33, $p < 0.001$). We did not show a significant effect for SESSION, nor a significant SESSION x CONDITION interaction. Post-hoc analysis revealed that the faster the self-selected speed conditions the higher the cadence ($p < 0.001$ for all comparisons).

3.2. SLCrel and reliability analysis

There were not significant differences for slope and intercept between the sessions (t = 1.49, p = 0.14; t = 1.60, p = 0.12, for slope and intercept, respectively).

Examination of the SLCrel plots in T1 and T2 showed a positive linear relationship in each of the participants. In session T1, the average R^2 was 0.97 (± 0.032), and the R^2 range was 0.87- 0.99. In session T2 the average R^2 was 0.94 (± 0.096) and the R^2 range was 0.81- 0.99.

The individual slope and intercept of the SLCrel in each subject showed high reliability across the three month period (Table 3). MID values were 0.006 and 0.202 for slope and intercept, respectively. Fig. 1 shows an example of the linear regression in one subject across the two test sessions.

4. Discussion

This main goal of the study was to evaluate the reliability of the SLCrel in PD subjects. Our results show that, using five different self-selected gait speed conditions, the linear regression between SL and cadence is reproducible and does not decline after a period of three months. Our findings suggest that the utilized protocol [4,10] can be used to explore changes in the stride-cadence gait relationship in PD subjects.

We showed that PD patients were able to modulate their speed, SL and cadence across the five self-selected speed conditions. The values of the speed, SL and cadence were equivalent to those obtained in previous studies with PD subjects of similar age and disease severity [4,10]. However, in the current study the overall speed in the first session was significantly slower than that in the second session. Thus, although, the two sessions were conducted three months apart, it is likely that some familiarization or learning may have occurred. For instance, it has been reported that learning effects can be present even when practice is limited to a minimum [21]. We should point out that for the preferred condition the increment from T1 to T2 was an average of 0.02 m/s, an increment lower than the value defined as a clinical meaningful change (0.05 m/s) for gait speed in PD subjects [22]. Nevertheless, for intervention studies, our results stress the need for a group of PD patients not receiving the therapy in order to differentiate possible learning effects from potential therapeutic effects related to the intervention.

The modulation of SL and cadence across the different self-selected speed conditions followed a linear relationship in each patient. The R^2, intercept and slope values of these relationships were similar to those previously reported for PD subjects [4,10], suggesting that the SLCrel is a reproducible measure across studies, when using the protocol described in Egerton et al. [18]. Importantly, in the current study both, the intercept and the slope, showed high reliability (CCI > 0.8) [23] across a three month period in PD patients. To our knowledge this is the first study that evaluated the reliability of the SLCrel in PD patients. The high reliability of the intercept is of relevance since this parameter represents one of the main deficits in the gait pattern of PD subjects, and thus may be a reliable measure to follow the progression of the disease.

In our study, the changes in the speed across the testing sessions did

Table 3
Reliability of SLCrel.

SLCrel T1 vs T2								
	Mean (SD) T1	Mean (SD) T2	t	p	ICC	95% CI	SEM	MID
Slope	0.015 ± 0.005	0.014 ± 0.006	1,618	.115	.897	.804-.950	0.002	0.006
Intercept	1.309 ± 0.169	1.338 ± 0.194	−1.661	.106	.908	.819-.953	0.073	0.202

Note. SLCrel, stride length - cadence relationship;SD, standard deviation; t, critical value; p, significance (paired samples *t*-test between tests 1 and 2); ICC, intraclass correlation coefficient; CI, 95% confidence interval, SEM, standard error mean; MID, minimal important difference.

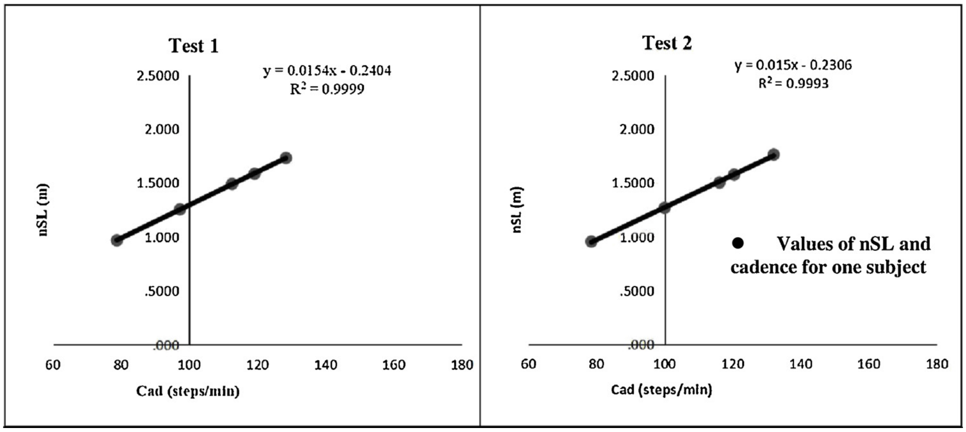

Fig. 1. SLCrel in the speed condition for one subject in T1 and T2.

not affect the SLCrel. In another words, an improvement or change in gait speed after a physical therapy intervention does not necessarily mean a change in the SLCrel. Thus, an improvement of speed, cadence or SL may represent a successful intervention, at least from a functional point view. However, if the SLCrel values do not change, these improvements may only reflect a general benefit from the practice of exercise during the therapy. In contrast, an increase of the intercept value of the SLCrel, indicates that there is a specific therapeutic effect on the gait in PD patients. Therefore, we propose that one of the main targets of physical gait therapies in PD should be the normalization of the SLCrel, by increasing the intercept value of this relationship. In order to use SLCrel as an outcome measure, in addition to good reliability, it must also be responsive to change. Levodopa therapy and the use of attentional or sensory cues strategies have been proven effective in improving the SLCrel in PD subjects [6]. Our findings suggest that an intercept increase of 0.202 m is the minimal important difference, in order to detect a change that can be attributed to the therapeutic intervention.

Our study presents several limitations that must be addressed. First, the PD participants were able to walk without assistance and thus, it is possible that the gait protocol used to evaluate the SLCrel may not be applied to patients with greater disease severity. Second, we evaluated the reliability of the SLCrel across a period of three months. We choose this period of time since most of the physical therapy studies used similar periods of intervention [11]. Future studies are warranted in order to examine the SLCrel evolution across the progression of the disease. In fact one study [24], using a different methodology than the current our study, showed a negative correlation between the time of diagnosis of PD patients and the contribution of the step length to the walking speed. These findings suggest that the SLCrel may be an effective marker of the disease progression. Another limitation of the current study is the non-inclusion of an age/sex matched control group in order to discern the expected change in healthy subjects and therefore, better understand the impact of the Parkinson's disease in the SLCrel.

In conclusion, the current study shows that the SLCrel in Parkinsonian gait is a reliable measure across a period of three months. We showed that the intercept and slope values, of the linear relationship between the gait parameters, remain unaffected even when changes in the gait speed are observed. Thus, the SLCrel, over a variety of self-selected speed conditions, may be a reliable tool to differentiate the specific from the general benefits of gait rehabilitation interventions in PD subjects.

Conflict of interest

All authors have no conflict of interest. This work was supported by Ministerio de Ciencia, Innovación y Universidades (DEP2017-87384-R), Spain

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